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Geographic variation in *Mesalina watsonana* (Sauria: Lacertidae) along a latitudinal cline on the Iranian Plateau

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Iran is geologically structured by several major mountain ranges, plateaus and basins, including the Zagros and Elburz Mountains, the Central Plateau, and the Eastern Highlands (Berberian & King 1981). *Mesalina watsonana* (Stoliczka, 1872) is one of the 14 species of the genus *Mesalina* Gray, 1838 and has a wide distribution range in Iran, Afghanistan, Pakistan, NW India and some parts of Turkmenistan (Anderson 1999, Rastegar-Pouyani et al. 2007, Khan 2006). It is well known that size and morphological adaptations of a species are closely linked to its habitat selection, determine its capability of colonising an area, and play an important role in the organisation of ecological communities (Peters 1983, Calder 1984, Schmidt-Nielsen 1984). Body size and morphology are often associated with latitude according to Bergmann's rule (Bergmann 1847, Mayr 1956). Squamates can be described as largely following an inverted Bergmann's rule, with the larger animals preferably colonising the warmer environments of lower latitudes (Ashton et al. 2000, Ashton & Feldman 2003, Blanckenhorn & Demont 2004), although there are exceptions, e.g., at intraspecific level amongst the lizards of genus *Sceloporus*, where larger individuals inhabit higher latitudes (Sears & Angilletta 2004). *M. watsonana* is widespread, occurring virtually at all altitudes represented within its range. Our study aimed at quantifying the variability of its morphological patterns within Iran by analysing the metric and meristic characters of individuals from two different latitudinal zones (26°N to 32°N and 32°N to 38°N; Fig. 1). To this end, we examined a total of 60 individuals from 34 localities (grouped into three geographical units, i.e., Zagros, East, and South; Tab. 1) for 28 morphological characters (Tab. 2). The collected specimens were fixed in 96% ethanol and are now deposited in the Sabzevar University Herpetological Collection (SUHC).

We also examined the extent of sexual dimorphism as evident in the 28 metric and meristic characters examined between the 39 adult males (15 Zagros; 10 South; 14 East) and 21 adult females (Tab. 3) by means of statistical analysis. The analyses were run using ANOVA and with SPSS 16.0 for a Principal Component Analysis (PCA) based on the correlation matrix of seven characters to identify groups that were possibly clustered. While 21 of the character states examined proved to show no significant variation between the two latitudinal zones, the seven that had P-values of < 0.05 (Tab. 4; HH, HL, TD, IOR, LV, LBT and LWB; see Tab. 2 for explanation of abbreviations used) in-

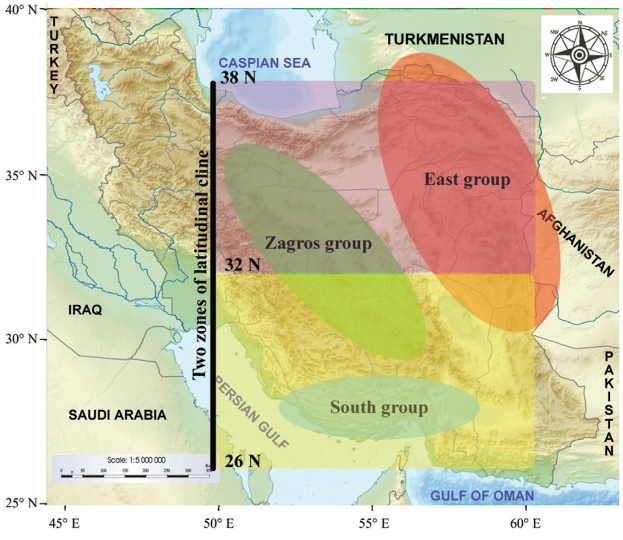

Figure 1. Iran, showing the two ranges of latitudes that were sampled and the three sampled geographical groups.

Table 1. Collection localities of *Mesalina watsonana* in Iran.

N°	E°	Altitude (m)	Locality
28° 37' 02.4"	054° 20' 29.7"	1103	Fars province, Darab-Tol rigi village
28° 27' 56.5"	054° 14' 25.4"	1111	Fars province, Lar
26° 58' 35.3"	054° 34' 27.4"	285	Hormozgan province, Bastak
29° 14' 45.4"	054° 22' 59.1"	1689	Fars province, Neyriz
27° 47' 33.6"	053° 47' 17.0"	939	Fars province, Evaz
26° 48' 43.1"	054° 10' 35.0"	37	Hormozgan province, Parsian
35° 09' 14.7"	059° 23' 39.6"	1382	Khorasan Razavi province, Roshtkhar
34° 56' 44.6"	059° 42' 51.3"	1249	Khorasan Razavi province, Khaf
34° 24' 23.1"	060° 16' 02.7"	969	Khorasan Razavi province, Sangan
34° 12' 24.6"	060° 16' 10.4"	741	Khorasan Razavi province, Chah gaz kohne
34° 59' 59.9"	058° 03' 26.4"	1176	Khorasan Razavi province, Bardaskan
33° 50' 32.5"	056° 22' 24.6"	1079	Yazd province, Tabas
36° 39' 16.1"	059° 19' 40.9"	1280	Khorasan Razavi province, Chenaran
34° 46.99'	057° 22.27'	1080	Khorasan Razavi province, Chah mosafer
33° 15.29'	058° 51.64'	1401	South Khorasan province, Arian Shahr
33° 49.40'	058° 19.66'	1306	South Khorasan province, Ferdows
33° 37.68'	060° 04.08'	955	South Khorasan province, Qaien
27° 17.57'	056° 28.977'	– 8	Hormozgan province, Bandar-e-abbas
27° 08.16'	055° 48.64'	12	Hormozgan province, Bandar-e-khamir
26° 46.59'	056° 04.17'	– 9	Hormozgan province, Qeshm
27° 02.65'	053° 15.11'	0	Hormozgan province, Neyrom
34° 17' 03.3"	051° 40' 42.0"	870	Isfahan province, Kashan
36° 32' 15.7"	058° 08' 15.1"	1330	Khorasan Razavi province, Mashkan
36° 36' 59.8"	057° 16' 42.4"	1367	Khorasan Razavi province, Joqatai
34° 32' 49.9"	060° 11' 07.0"	1061	Khorasan Razavi province, Salami
35° 46' 41.5"	060° 36' 00.9"	1306	Khorasan Razavi province, Torbat-e-Jam
35° 10' 21.7"	060° 58' 23.6"	814	Khorasan Razavi province, Doab-Torbatjam
34° 44' 01.9"	060° 48' 50.0"	795	Khorasan Razavi province, Taybad
35° 32' 12.8"	059° 11' 51.9"	1711	Khorasan Razavi province, Torbat-e-Heydariyeh
33° 08' 12.6"	056° 17' 11.1"	1267	Sistan region, Zabol
32° 55' 41.3"	055° 31' 11.1"	1544	Yazd Province, Robat-e-Posht badam
30° 51' 33.8"	052° 50' 33.7"	2316	Fars province, Eghlid-
29° 59' 49.4"	051° 17' 27.7"	1183	Fars province, Nourabad-Babameydan
30° 18' 53.3"	053° 54' 48.8"	2065	Fars province, Bavanat-Toot Syiah area

dicated a cline between low and high latitudes in that they increased from south to north.

Results from the Principal Component analysis (Tab. 5) indicated that the first PC explained more than 66% of the total variation in seven character states, and the second PC explained more than 77% of the total variation in the same seven character states. PC1 is heavily weighted by LBT and IOR, and PC2 is heavily weighted by TD (see PCA scatterplot in Fig. 2). Variation in precipitation was approximately equally distributed across the first three PCs. Furthermore, a Principal Component Analysis yielded a primary axis that suggests LBT to be very significant. The PCA analysis also produced a secondary axis that is negative for most characters.

According to a Discriminant Function Analysis (DFA) head height predicted the originally grouped samples almost correctly (80.0% for the latitudinal range 26–32°, and 79.3% for 32–38°). Also based on this analysis, head length classified the original grouped cases almost correctly, so that 70% for range latitude between 26–32° and 69% for range latitude between 32–38 ° were correctly classified into their relevant groups.

Regression plots drawn from these statistics for seven characters (Figs. 3, 4), show a fairly marked positive relationship between increased latitude and character expression.

Oraei et al. (2011) demonstrated that sexual dimorphism was also evident in other meristic characters of *Mes-*

Table 2. Morphometric characters analysed in the present study.

Character	Definition
SVL	Snout–vent length
TL	Tail length
LHF	Trunk Length
HL	Head Length
HH	Head Height
HW	Head width
LFL	Length of forelimb
LHL	Length of hindlimb
LFO	Length of femur
LA	Length of tibia
EL	Horizontal diameter of eye
RED	Snout length
EED	Distance between posterior edge of eye and tympanum
NL	Length of neck
TD	Tympanum diameter
IOR	Interorbital distance
LV	Length of cloacal opening
LBT	Maximum width of tail base
LWB	Maximum width of belly
NSL	Number of labial scales anterior to the centre of eye
NIL	Number of scales on the Infralabials
NGS	Number of gular scales in a straightedian series
NCS	Number of collar scales
NEE	Number of scales between posterior edge of eye and tympanum
NVS	Number of transverse series of ventral scales
NDS	Number of dorsal scales acrossidbody
SDLT	Number of subdigital lamellae (4th toe)
NFP	Number of femoral pores

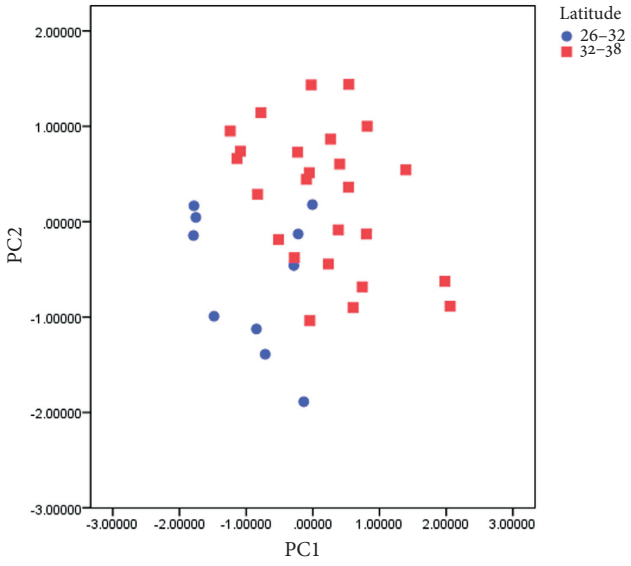

Figure 2. Principal components of seven characters as per collection sites.

alina watsonana. The ANOVA analysis of our material showed that most of the characters considered were significantly sexually dimorphic ($P < 0.05$) for each group separately (Tab. 3).

Latitude is often one of the determining factors of climate, affording animals at lower latitudes with warmer conditions for longer periods of time that in turn facilitate longer periods for reproduction (Pincheira-Donoso et al. 2008).

According to our ANOVA analysis, seven characters (Tab. 4) are significantly different between specimens from the two latitudinal zones examined (P-values < 0.05), which means that these character states display two different patterns of variation corresponding to the two selected latitudinal zones (Fig. 1). The PCA scatterplot shows their separation clearly, with the samples from higher latitudes being located near the maximum ranges (Fig. 2). The subsequent regression plots then show that these character states vary with latitude. According to Ashton et al. (2000), Bergmann's rule is true for mammals and birds (endotherms). Our results confirm Bergmann's rule for *M. watsonana* to a

Table 3. The ANOVA-based intrasexual comparison of meristic and morphometric character states in three different population groups of *Mesalina watsonana*. Degrees of freedom = 1. Significant characters in each group are emphasised in bold. Abbreviations: F = F value, Sig. = Significance as P-value.

	Eastern and Northeastern group				Zagros group				South group			
Character	Sum of Squares	Mean Squares	F	Sig.	Sum of Squares	Mean Squares	F	Sig.	Sum of Squares	Mean Squares	F	Sig.
SVL	48.989	48.989	2.358	0.138	73.342	73.342	8.697	**0.007**	0.686	0.686	0.156	0.703
TL	404.609	404.609	1.737	0.217	203.075	203.075	3.477	0.095	16.465	16.465	0.037	0.854
LHF	0.008	0.008	0.001	0.974	13.279	13.279	1.925	0.179	5.402	5.402	1.121	0.321
HL	12.046	12.046	14.251	**0.001**	0.762	0.762	0.697	0.412	1.176	1.176	8.683	**0.019**
HH	3.871	3.871	10.992	**0.003**	3.397	3.397	3.116	0.091	0.090	0.090	1.014	0.344
HW	5.176	5.176	9.045	**0.006**	1.049	1.049	0.820	0.375	0.365	0.365	7.626	**0.025**
LFL	18.553	18.553	9.573	**0.005**	0.001	0.001	0.001	0.979	1.537	1.537	1.678	0.231
LHL	104.995	104.995	18.547	**0.000**	20.803	20.803	6.182	**0.021**	16.978	16.978	7.056	**0.029**
LFO	2.697	2.697	4.230	0.051	0.674	0.674	1.829	0.189	0.955	0.955	0.912	0.368
LA	7.762	7.762	13.503	**0.001**	0.164	0.164	0.313	0.581	0.497	0.497	2.284	0.169
EL	0.697	0.697	3.833	0.063	0.082	0.082	0.355	0.557	0.876	0.876	4.321	0.071
RED	2.569	2.569	8.436	**0.008**	0.282	0.282	1.078	0.310	0.557	0.557	1.413	0.269
EED	0.420	0.420	1.201	0.285	0.432	0.432	3.357	0.080	0.096	0.096	0.732	0.417
NL	0.603	0.603	0.939	0.343	3.683	3.683	7.284	**0.013**	0.835	0.835	1.045	0.337
TD	0.272	0.272	8.529	**0.008**	0.179	0.179	2.340	0.140	0.059	0.059	0.986	0.350
IOR	0.957	0.957	2.755	0.111	0.287	0.287	2.958	0.099	0.055	0.055	6.879	**0.031**
LV	5.816	5.816	7.611	**0.011**	2.863	2.863	3.137	0.090	3.600	3.600	13.516	**0.006**
LBT	7.278	7.278	5.492	**0.028**	2.786	2.786	4.632	**0.042**	1.384	1.384	18.025	**0.003**
LWB	5.093	5.093	1.599	0.219	7.480	7.480	6.997	**0.014**	0.967	0.967	4.504	0.067
NSL	0.935	0.935	4.246	0.051	0.250	0.250	0.742	0.398	0.900	0.900	2.250	0.172
NIL	0.000	0.000	0.001	0.982	0.250	0.250	0.418	0.524	0.400	0.400	0.889	0.373
NGS	0.416	0.416	0.155	0.697	1.210	1.210	0.503	0.485	0.400	0.400	0.081	0.783
NCS	3.617	3.617	2.906	0.102	5.760	5.760	4.665	**0.041**	0.400	0.400	0.276	0.614
NEE	0.000	0.000	0.000	1.000	0.810	0.810	0.841	0.369	0.000	0.000	0.000	1.000
NVS	13.149	13.149	9.206	**0.006**	7.840	7.840	6.092	**0.021**	0.100	0.100	0.125	0.733
NDS	1.877	1.877	0.098	0.758	6.760	6.760	0.393	0.537	2.500	2.500	0.079	0.785
SDLT	0.998	0.998	0.517	0.479	4.410	4.410	1.806	0.192	28.900	28.900	14.821	**0.005**
NFP	0.458	0.458	0.276	0.604	0.040	0.040	0.026	0.873	0.400	0.400	0.400	0.545

Table 4. Results of ANOVA-based intragroup comparisons of morphometric and meristic character states of Iranian *Mesalina watsonana* collected for the present study. Degrees of freedom = 1. Significant characters in each group are emphasised in bold. Abbreviations: F = F value, Sig. = Significance as P-value.

Character	Sum of Squares	Mean Squares	F	Sig.
SVL	65.037	65.037	4.389	0.053
TL	346.234	346.234	1.914	0.186
LHF	13.866	13.866	1.826	0.185
HL	3.740	3.740	4.717	**0.036**
HH	6.039	6.039	17.410	**0.000**
HW	2.457	2.457	3.559	0.067
LFL	1.179	1.179	0.553	0.462
LHL	3.752	3.752	0.812	0.373
LFO	0.221	0.221	0.393	0.535
LA	1.561	1.561	2.792	0.103
EL	0.119	0.119	0.484	0.491
RED	0.841	0.841	2.402	0.130
EED	0.363	0.363	1.891	0.177
NL	0.122	0.122	0.175	0.678
TD	0.370	0.370	4.952	**0.032**
IOR	1.233	1.233	4.862	**0.034**
LV	7.537	7.537	9.772	**0.003**
LBT	6.763	6.763	7.341	**0.010**
LWB	11.991	11.991	6.028	**0.019**
NSL	0.102	0.102	0.325	0.572
NIL	0.385	0.385	0.694	0.410
NGS	0.085	0.085	0.032	0.859
NCS	0.580	0.580	0.399	0.531
NEE	1.129	1.129	0.742	0.395
NVS	0.096	0.096	0.087	0.770
NDS	28.929	28.929	1.575	0.217
SDLT	6.256	6.256	1.813	0.186
NFP	0.732	0.732	0.452	0.506

Table 5. Factor loadings on first three principal components elicited from a correlation matrix of seven morphological characters of 39 male *Mesalina watsonana* used in the present study.

Character	PC1	PC2	PC3
HH	0.827	-0.027	0.287
HL	0.838	0.062	-0.446
TD	0.580	0.794	0.117
IOR	0.884	-0.058	-0.140
LV	0.793	-0.152	0.504
LBT	0.885	-0.271	0.061
LWB	0.858	-0.092	-0.304
Eigen values	4.651	0.743	0.665
% of variance	66.443	10.616	9.503
Cumulative	66.443	77.059	86.559

certain extent in that they provide clear evidence that some metric character states increase with latitude, while snout–vent length (SVL) remains relatively constant.

In Iran, increasing latitudes correspond with decreasing average temperatures (Dastorani & Poormohammadi 2012). According to Oufiero et al. (2011), lizards have larger scales in warmer environments to reduce the risk of overheating and smaller ones in cooler environments to improve heat retention. In Iranian *M. watsonana*, the size of the head gradually increases with latitude, and we assume that this change in head size is related to environmental conditions.

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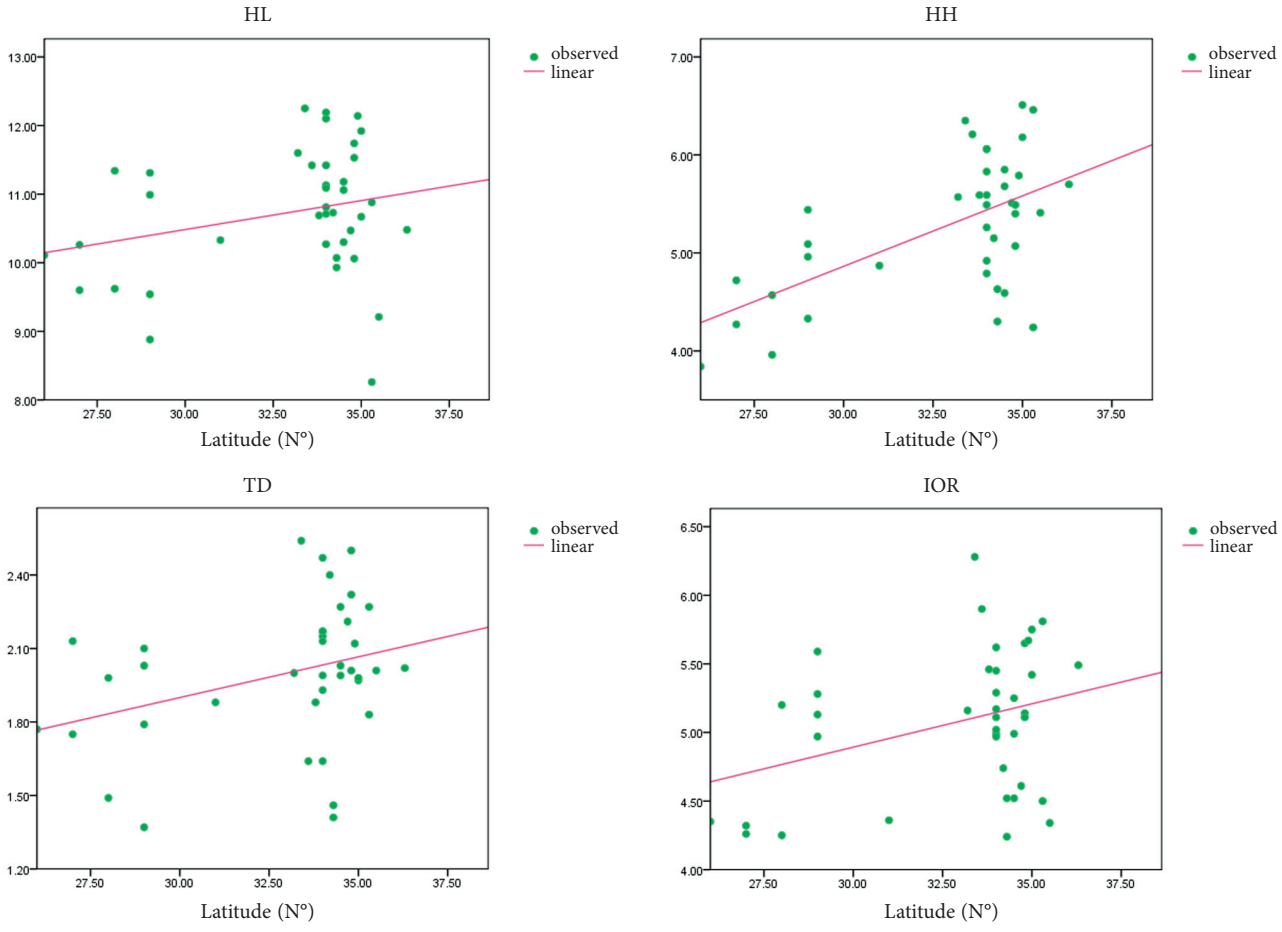

Figure 3. ANOVA-significant regression plots of four characters (HL, HH, TD and IOR).

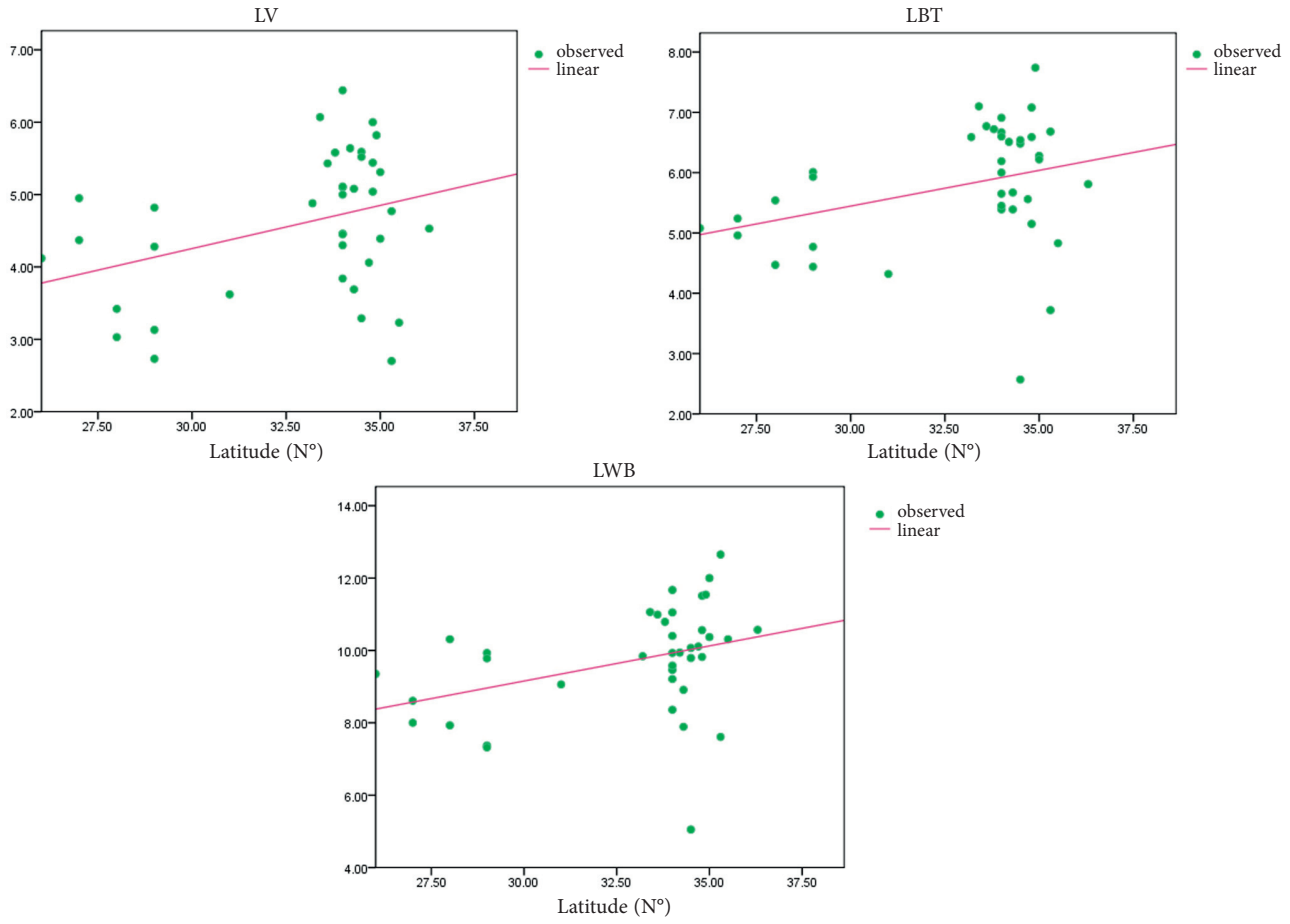

Figure 4. Regression plotted for three characters, LV, LBT and LWB, and their ANOVA significance.

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